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Effects of different factors on drivers' guidance compliance behaviors under road condition information shown on VMS

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ABSTRACT

It is generally accepted that compliance behavior is affected by many factors. The purpose of this study is to investigate the effects of diverse factors on drivers' guidance compliance behaviors under road condition information shown on graphic variable message sign (VMS), and based on this to find out a better information release mode. The involved data were obtained from questionnaire survey, and ordinal regression was used to analyze the casual relation between guidance compliance behavior and its influencing factors. Based on an overall analysis of conditions in driver's route choice, an accurate method was proposed to calculate the compliance rate. The model testing information indicated that ordinal regression model with complementary log–log being the link function was appropriate to quantify the relation between the compliance rate and the factors. The estimation results showed that age, driving years, average annual mileage, monthly income, driving style, occupation, the degree of trust in VMS, the familiarity with road network and the route choice style were significant determinants of guidance compliance behavior. This paper also compared two different guidance modes which were ordinary guidance mode (M1) and predicted guidance mode (M2) through simulation. The average speed fluctuations and average travel time supported that M2 had better effect in improving traffic flow and balancing traffic load and resource. Some detailed suggestions of releasing guidance information were proposed with the explanation by flow-density curve and variation of traffic flows. These findings are the foundation to design and improve guidance systems by assessing guidance effect and modifying guidance algorithm.

1. Introduction

Urban traffic guidance system, which can efficiently alleviate traffic congestion and greatly improve the performance of traffic system, is a great part of intelligent transport system (ITS). Variable message sign (VMS), as an infrastructure of urban traffic guidance system, is a main platform to release guidance information. VMS can provide drivers with traffic information, including road conditions, abnormal traffic events, and traffic safety campaigns, by gathering, processing and disseminating dynamic and nearly real-time traffic information. Meanwhile, releasing traffic information is also a means of traffic dispersion, which can guide drivers to avoid congested roads, balance the traffic load on network and make the best use of roads resource.

Nevertheless, unlike traffic control signal, the guidance information is just a kind of suggestion message, and it has no mandatory effect on drivers. So drivers can choose to comply with the VMS or not. Compliance rate is used to represent the drivers' compliance degree on guidance information. The rate is the proportion of drivers who select the suggested roads

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of VMS just because of the existence of VMS, and it reflects the effects of guidance information on drivers' compliance behavior. In this paper, compliance rate is the probability of drivers selecting the suggested roads among their multiple selections.

In previous studies, drivers were generally assumed to comply with guidance information completely (Ericsson et al., 2006; Fu, 2001; Kanafani and Al-Deek, 1991; Lo and Szeto, 2002; Piyushimita and Ashish, 1996; Wang et al., 2006) or select paths according to a fixed rate (Francesco, 2003; Mammar et al., 1996; Papageorgiou, 1990; Yin and Yang, 2003), this is not realistic. Many researches declared that drivers preferred the information about accident, congestion or alternative routes, but the proportions of drivers who really changed routes were distinct, rarely more than 40%. Cummings (1994) found only 4–7% of the drivers chose to switch routes, Lindkvist (1995) found 5–25% of the drivers chose the alternative routes, Ramsy and Luk (1997) found the switching rate reached to 30% when traffic congestion information was released, Davidsson and Taylor (2003) found 6–41% of the drivers would choose alternative roads to avoid congestion in Sweden. Compliance rate varied significantly as the compliance behavior of drivers closely depended on their characteristics, their perception of the guidance information, the information content, their familiarity with road network, and even their mood when they saw the VMS. Furthermore, the dependency changed gradually while the drivers gained more knowledge of VMS (Adler et al., 1993; Bonsall, 1992a; Bonsall and Palmer, 1998; Bonsall and Parry, 1990; Chen et al., 1999; Khattak et al., 1991; Lai And Yen, 2004; Chen and Mahmassani, 1993; Yang et al., 1993). A known compliance rate was the foundation of effective traffic guidance system, thus it was very important to study the factors that affected the perception and guidance compliance behavior of drivers (Koutsopoulos and Xin, 1993; Ozbay and Bartin, 2004).

Bonsall (1992a) proposed that individual route choice was affected by a number of factors, including expected journey time, delays, congestion, information-related routes, costs, safety and security hazards, the familiarity with the routes and information quality. Bonsall and Palmer (1998) demonstrated that information about accidents, delays and congestion shown on VMS had a significant influence on route choice, and the influence was very dependent upon the wording of the message. Lai and Yen (2004) conducted a questionnaire survey to investigate drivers' attention, preference and the response to VMS, the results indicated that 69.23% of the drivers were aware of the existence of VMS while they were driving. The display characteristics, such as font, color and phrasing, and the socio-economic characteristics, such as age, gender and education, were significant factors which influenced drivers' preference and response. Yang et al. (2005) carried out an ergonomic study to assess drivers' response and preference to different information characteristics, the results indicated that a combination of three colors on VMS took longer time to respond than one or two, and drivers preferred to yellow, green or yellow and green.

Most previous researches focused on pure text-based VMS (Anttila et al., 2000; Cooper et al., 2004; Dutta et al., 2004; Erke et al., 2007; Rämä and Kulmala, 2000; Wardman et al., 1997). Dutta et al. (2004) conducted a driver simulator study with two consecutive screens presenting text messages in the USA. The messages were repeated or not, the presentation time was 0.5 s per word for repeated messages and 1 s for unrepeated ones. The result indicated that the miss rate of unrepeated messages was significantly higher than the repeated ones. Cooper et al. (2004) reported about a study on text messages involved numerals carried out in England. A text message with a certain font and capital height had low legibility, widening the spacing between the numerals or using the different numeral fonts could increase the legibility. The legibility was also enhanced when difficult words were shown in another format, such as upper case letters, or using a pictogram instead the difficult words.

Compared to the text-based VMS, fewer researches about symbolic and graphic VMS were conducted (Alferdinck et al., 1998; Choi and Tay, 2008; Luoma and Rämä, 2001; Tay and Choi, 2009). Luoma and Rämä (2001) interviewed 795 voluntary drivers from six countries including England, Finland, France, Germany, Greece and Netherland on graphic VMS. The results showed that age, gender and driving experience had no significant effect on interpreting the VMS, whereas country had. It might be due to the diversity of graphic VMS in different countries. Tay and Choi (2009) redesigned the graphics of traffic control information in Seoul of Korea and presented them on VMS to test and assess. They found out that most of the graphics were easy to understand, but some were not, such as the graphics of traffic accidents, congestion and snow information. Furthermore, some scholars compared the effects of text-based and graphic VMS on drivers' behaviors (Kosonen and Luoma, 1994; Nuttall et al., 1998; Rämä et al., 2004). Kosonen and Luoma (1994) compared wet road surface information shown on text-based and graphic VMS to determine what kind of VMS should be used. Rämä et al. (2004) found graphic VMS was preferred by drivers despite they might not understand it correctly. Nuttall et al. (1998) pointed out the recognition process of symbols or graphics was very different from characters, it took drivers more attention and longer distance to read text messages.

Graphic VMS is used widely in practice (Balz, 2003; Sara and Gabriel, 2007; Stainforth, 2004). Western European Road Directors and Deputies (WERD) was in favor of a set of common graphic VMSs being used in European countries (Stainforth, 2004). Conference of European Directors of Roads (CEDR) suggested that some new and sufficient graphic VMSs should be used in certain situations. Balz (2003) proposed to use easy-to-understand symbols and pictograms as much as possible in some areas for harmonization. Language-independent was the advantage of symbols and pictograms. It allowed drivers from different countries to read, of course, pure graphic information was not enough sometimes, especially when the notification was presented, and supplementary text information might be needed (Sara and Gabriel, 2007).

Owing to the significant difference between the effects of text-based and graphic VMSs on drivers' behaviors, the findings of text-based VMS research cannot be immediately applied to design and use the graphic VMS, it was necessary to study the graphic VMS separately. The aim of this research was to study the effects of different factors on drivers' guidance compliance behaviors under road condition information shown on graphic VMS and find out a better information release mode.

2. Object

The graphic VMS we chose to study is placed near the east gate of Renmin University of China and about 300 m away from SITONG Bridge along the southbound direction (Fig. 1). The VMS presents the current traffic conditions of two horizontal and three vertical roads ahead to the passing drivers. Red, yellow and green shown on the VMS indicate that the road is very congested, generally crowded and smooth, respectively. The information shown on VMS is updated every 5 min. The sections, between JIMEN Bridge and XIZHIMEN Bridge and between SUZHOU Bridge and ZIZHU Bridge, are both expressways, which means there are no signalized intersections in these two roads (i.e., there are no control delays). However, there are four signalized intersections with control delays on the section between SITONG Bridge and BAISHIXIN Bridge. Fig. 2 shows the road network closely related to the VMS, and the roads which are marked in cyan are shown on VMS.

The reason why we choose this VMS to study, for one thing, is the suitable distance between the VMS and SITONG Bridge, the travel time from VMS to downstream road is not too long or too short, so the real-time performance of VMS is not affected, and also drivers have enough time to switch after passing the VMS; for another thing, is the slight differences among the travel times of different paths shown on VMS when the flow is free, the ambilateral paths are mainly comprised of

Fig. 1. Graphical VMS.

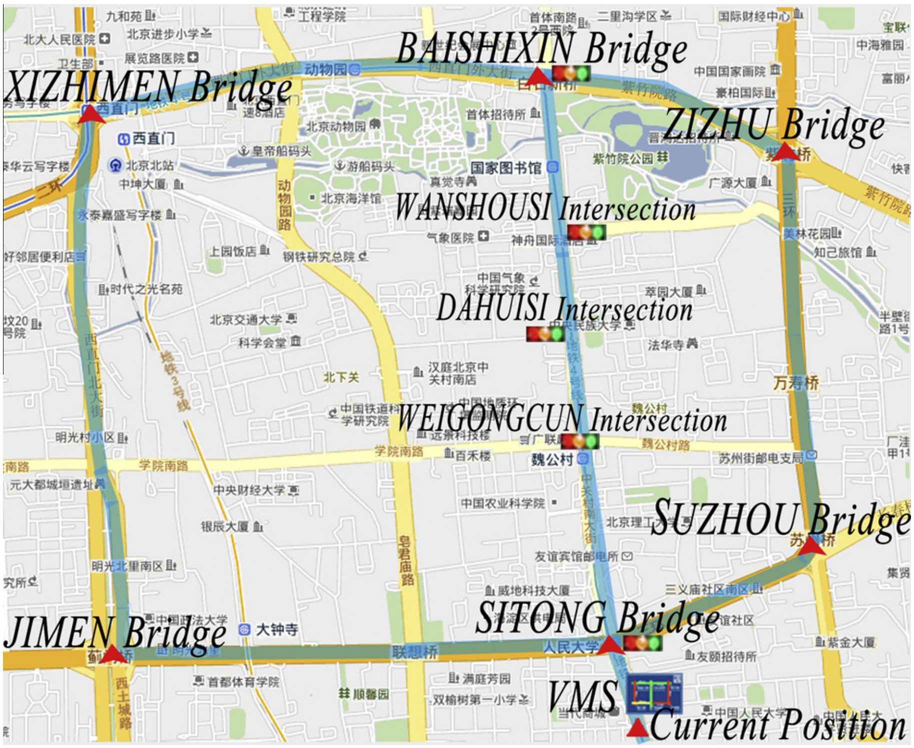

Fig. 2. Road network information.

expressways with design speed being 80 km/h, the middle paths are comprised of truck roads with design speed being 60 km/h, but the length of ambilateral paths are generally longer than the middle paths. Considering the above reasons, the effects of VMS are more obvious, and studying on it can better reflect drivers' routing preference.

Questionnaire survey (Bonsall and Joint, 1991; Cummings, 1994; Chen et al., 2006; Mo and Yan, 2007; Zhou and Wu, 2006) and computer simulation were our pivot methods. In the survey, scene simulation was also carried out to study the drivers' route choice behaviors under different road condition information shown on VMS.

3. Questionnaire survey and analysis

3.1. Questionnaire and data design

Several real guidance scenes simulated in the questionnaire were conducted to investigate the route choice behavior. Besides the scene simulations, drivers' socio-economic characteristics and travel characteristics were the other two parts investigated in the questionnaire.

Drivers' socio-economic characteristics were gender, age, driving years, average annual mileage, monthly income, educational level, driving style (i.e., risk-based, steady or conservative), occupation and type of car (i.e., private car or service car). Drivers' travel characteristics included driving goal (i.e., saving time, saving fuel or depending on circumstance), the familiarity with network (i.e., very familiar, generally familiar or not familiar), route choice style (i.e., one always chose a fix route to one place, which was known as fixation type; one chose route based on his experience, which was known as experience type; one chose route based on his experience and some other information, which was known as experience and information type; one chose route just according to the guidance information shown on VMS, which was known as guidance information type), the trust degree in the VMS, the routes to specific destinations (one participant should chose two destinations, one is a frequented destination ***A*** and the other is a random destination ***B*** where the driver may often go, occasionally go or never go before) under different information shown on VMS (there were 24 selections in a questionnaire, 12 for ***A***, 12 for ***B***), and at last the rank of some factors affecting their route choice.

According to field observation, 12 kinds of typical guidance information were refined from some specific time periods including the morning peak, evening peak and some normal time, and shown on VMS in the scene simulation part of questionnaire (Fig. 3). Fig. 3a was a control group which indicated that all roads were smooth, and Fig. 3b–l were experimental groups. Drivers chose the best route based on their experience under 3a, and based on their experience and guidance information under 3b to 3l. Each driver should mark their familiarity level with these scenes, including very familiar, relatively familiar, familiar, unfamiliar and very unfamiliar, when he chose the routes. For instance, a driver always encountered scene 2 as he just passed the VMS on and off duty, so he was very familiar with scene 2, whereas another driver often encountered the VMS at weekend, so he was unfamiliar with scene 2.

In April 2011, we investigated the masses around the vicinity of the VMS, including the subway stations along the road, huge shopping malls, schools and hospitals, where many people gathered together. We recorded the cell phone numbers and email addresses of people who were willing to participate in. Then the questionnaires were sent out to the participants and retrieved through the internet. Each respondent was paid a 30 yuan mobile phone recharge card. Totally, 423 questionnaires were sent out and 328 questionnaires were retrieved, recovery rate reached at 77.5%.

3.2. Data analysis

The drivers who would be affected by VMS but not just by VMS in their route choice processes were chosen to be analyzed. Only in this way could we study the drivers' responses to the VMS and the factors affecting the compliance behaviors. So a question was designed to determine drivers' route choice style from fixation type, experience type, experience and information type, and guidance information type. Through the data analysis of received questionnaires, we found that it was not absolutely right for respondents to judge their route choice style, for example, many drivers choosing fixation type were affected by VMS in fact. Hence, we chose the experience and information type from the respondents through their self-judgment, their actual chosen paths and the ranking result of different factors. This was one of our standards to select sample. In the 328 recovered questionnaires, 246 valid questionnaires were finally obtained by selecting targeted sample, excluding questionnaires with missing data or conflicted answers. The valid rate was 75.0% and the number of path selection simulation was 5904 under different guidance scenes.

Different statistical methods can be used to analyze guidance compliance behavior data. These methods, including descriptive statistics, chi-square, linear regression analysis, logistic regression techniques, structure equations and ordinal regression analysis yield results with different focuses. Descriptive statistics, e.g., means, frequencies and standard deviation analysis are often applied to identify the distributions and trends of the data. Regression methods, e.g., linear, logistic and ordinal regression are used to analyze the relationship between multiple explanatory variables and dependent variable. The scene simulation could provide us with chosen routes in different scenes, whether drivers comply with the guidance or not, and the numbers of compliance among all the experimental scene groups. The data from questionnaire survey, representing the drivers' guidance compliance behaviors and their socio-economic and travel characteristics, were all discrete. It could be transformed into ordinal or nominal data based on certain standards (details see chapter 3.2.1 and 3.2.2). The

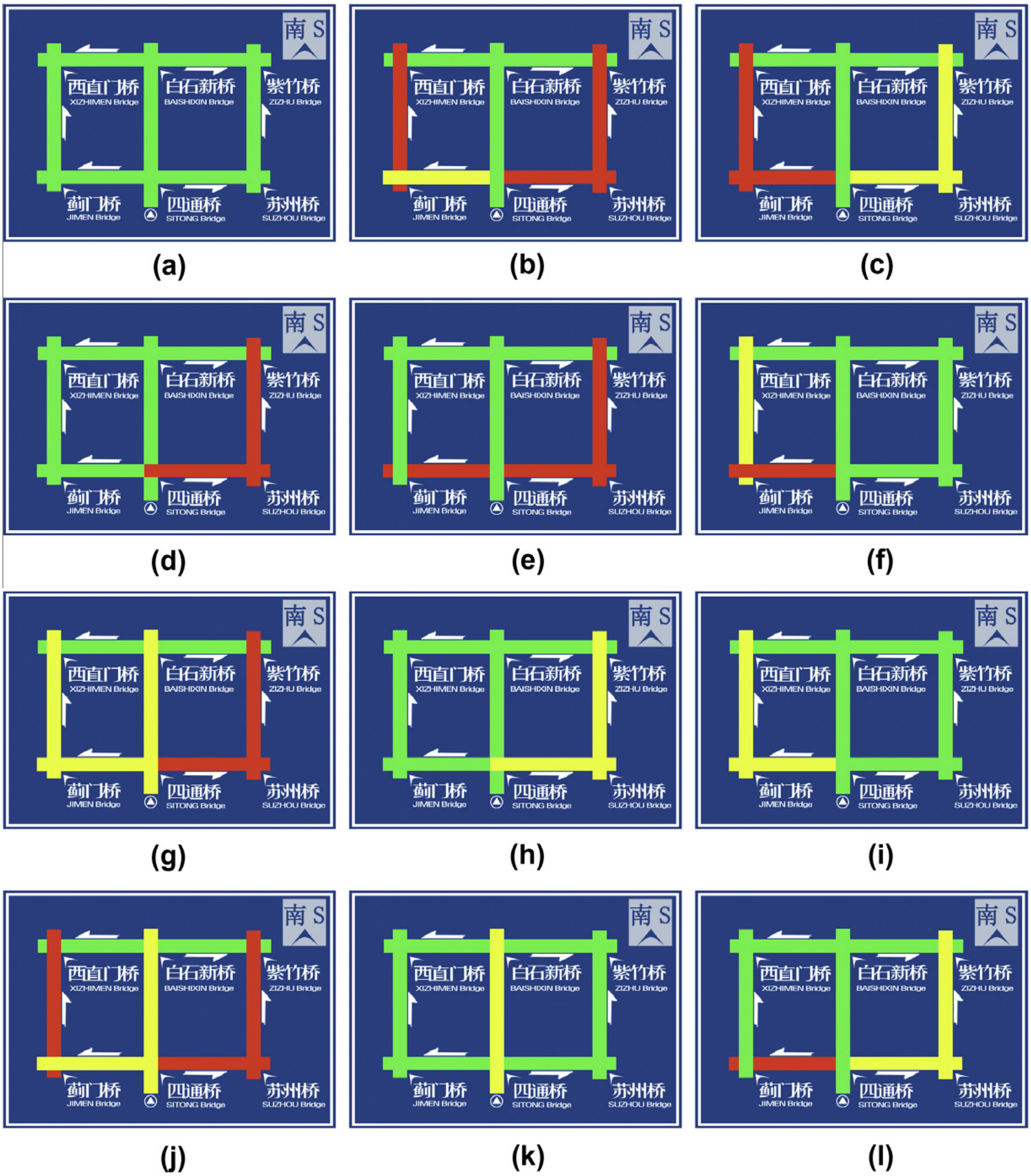

Fig. 3. (a) Scene 1, (b) scene 2, (c) scene 3, (d) scene 4, (e) scene 5, (f) scene 6, (g) scene 7, (h) scene 8, (i) scene 9, (j) scene 10, (k) scene 11, (l) scene 12.

compliance degree transformed from compliance numbers was defined as the dependent variable (details see chapter 3.2.1). As ordinal regression was very suitable to apply in such case, it was used to analyze the relation between guidance compliance behavior and its influencing factors.

In the 246 valid questionnaires, 67.9% of the respondents were male. 47.2% were younger than 30 years, 46.7% were 31–40 years and 6.1% were over 50 years old. About 61.8% of the respondents were company employees, 24.4% were government employees, and 13.8% were the other occupations including lawyer, teacher, and self-employed etc. Most of the respondents at least had one private car, and the remaining 11.8% did not have their own car. The drivers' driving years varied significantly with 21.1% being less than 1 year, 33.7% being 1–3 years, 17.9% being 3–5 years and 27.3% over 5 years. About 45.1% of drivers earned 5000 to 10000 yuan a month, 28.0% less than 5000 yuan, and 26.8% more than 10000 yuan.

3.2.1. Dependent variable analysis

How to decide the compliance numbers of drivers among the multiple selections was a crucial problem of our research. Recommended path of VMS, actual chosen path of driver, experiential path of driver and the trust degree in VMS of driver were synthetically considered to judge if the driver complied with the VMS. First, we introduced the concept of recommended path of VMS. That was the path with shortest travel time from current position to destination under the current guidance information shown on VMS. Travel time was denoted by T, calculated by the following formula:

$$T = \sum_{i=1}^{N_S} \frac{L_S^i}{\overline{V}_S^i} + \sum_{j=1}^{N_I} T_I^j$$

where N_S was the number of sections contained in the path selected by driver; L_S^i was the length of the ith section contained in the selected path; $\overline{V}_S^i$ was the average speed of the cars in the ith section with certain information shown on VMS; N_I was the number of intersections contained in the selected path; T_I^j was the delay to pass the jth intersection contained in the selected path.

L_S^i was obtained from electronic map (map.baidu.com) (see Table 1). $\overline{V}_S^i$ was the measured average speed corresponding to red, green and yellow shown on VMS (see Table 2). The intersection delays mainly existed in the section between SITONG Bridge and BAISHIXIN Bridge. T_I^j was also obtained through field measurement (see Table 3). Under a certain guidance scene denoted by c, the path with the shortest travel time was treated as the path that VMS recommended to drivers after travel time of all the paths between the current position and destination were calculated. The recommended path of VMS was denoted by P_{cg}. The path driver selected in the reference scene (i.e., the all green scene in Fig. 3a) was the experiential path denoted by P_e, the other paths driver selected in scene (i.e., one of the 11 scenes from Fig. 3b–l) was the actual path denoted by P_{cr}. The rules to determine whether the driver complied with the VMS under scene c were as follows:

(1) If P_{cg} was different from P_{cr}, then the driver was believed not to comply with VMS;
(2) If P_{cg} was the same with P_{cr}, and different from P_e, then the driver was believed to comply with VMS;
(3) If P_{cg}, P_{cr} and P_e were all the same, then the drivers was believed to comply with VMS at the probability of 100%, 50% and 0% corresponding to their trust degree in VMS being high, middle and low, respectively.

Table 1
Lengths of road sections.

Road section		Length (m)
SITONG Bridge	SUZHOU Bridge	1200
SITONG Bridge	BAISHIXIN Bridge	3200
SITONG Bridge	JIMEN Bridge	2700
SUZHOU Bridge	ZIZHU Bridge	2200
ZIZHU Bridge	BAISHIXIN Bridge	1400
BAISHIXIN Bridge	XIZHIMEN Bridge	2600
XIZHIMEN Bridge	JIMEN Bridge	3000

Table 2
Average car speeds responds to different colors shown on VMS.

Color	Red	Yellow	Green
Car Speed (m/s)	2.0694	4.9222	8.1278

Table 3
Intersection delays.

Intersections	SITONG Bridge	WEIGONGCUN intersection	DAHUISI intersection	WANSHOUSI intersection	BAISHIXIN Bridge
Left direction					
Stopped delay (s)	22.5	35.36	32.14	25.71	30.53
Driving delay (s)	13	5	4	8	0
Total delay (s)	35.5	40.36	36.14	33.71	30.53
Forward direction					
Stopped delay (s)	19.29	28.93	33.51	26.8	32.79
Driving delay (s)	5.1	5	3.5	4.5	0
Total delay (s)	24.39	33.93	37.01	31.3	32.79
Right direction					
Stopped delay (s)	0	0	/	0	0
Driving delay (s)	0	3	/	4.36	0
Total delay (s)	0	3	/	4.36	0

Guidance compliance rate is a relatively accurate quantification of guidance compliance behavior, so compliance rate is the beginning of studying compliance behavior in the previous studies (Chiu and Huynh, 2007; Ericsson et al., 2006; Lo and Szeto, 2002; Mammar et al., 1996; Papageorgiou, 1990). In our research, the compliance rate of each driver was calculated from the combination of the familiarity distributions of 11 guidance scenes (i.e., the familiarity degree with 11 guidance scenes of each driver) and whether he chose the suggested path in each guidance scene or not. The probability of running into each scene was converted from the familiarity degrees of 11 scenes, and whether he complied with the VMS was deduced from the above mentioned rules. Finally, the probabilities of the scenes under which the driver complied with the VMS were summed up, and it was the compliance rate.

The compliance rate was too discrete to conduct ordinal regression. To better use the ordinal relation presented by compliance rate, we defined compliance degree to be the dependent variable. If the compliance rate was more than 70%, the compliance degree was high; if the compliance rate was less than 30%, the compliance degree was low; if the compliance rate was between 30% and 70%, the compliance rate was middle.

3.2.2. Independent variables analysis and extraction

As previously mentioned, there were many factors influencing route switching and compliance behavior, including personal characteristics, such as age, gender, occupation etc., and travel characteristics, such as the familiarity with network, driving goal, route choice experience etc. In this paper, we extracted 13 factors through the analysis of questionnaire, including *gender, age, driving years, average annual mileage, personal monthly income, education lever, driving style, occupation, car type, driving goal, trust degree in VMS, the familiarity with road network and route choice style.* These factors were the source of independent variables in ordinal regression, the value of each variable was shown in Table 4.

Chi-square test was conducted between independent variables and dependent variable before regression analysis to verify their causal relation. The result of chi-square test was shown in Table 5. The independent variables with p-value being less than 0.25 were kept to be the candidate variables, so educational level ($P = 0.996$) and driving goal ($P = 0.384$) were excluded. In the survey, we were reported that saving time was the same with saving fuel in the urban road network by many respondents, and they were both required for dynamic shortest path. The result of chi-square test proved this point (i.e., no significant relation between driving goal and guidance compliance behavior).

Like the linear regression, ordinal regression model is also sensitive to the collinearity existing among the independent variables. Hence, collinearity diagnostics was applied to select independent variables. In linear regression model, tolerance and variance inflation factor (VIF) calculated by SPSS or SAS are the indexes to test collinearity. However, SPSS or SAS does not provide these indexes when ordinal regression model is used. As we focused on the collinearity of independent variables, and tolerance or VIF had nothing to do with the function forms of dependent variable in the model, we used a linear regression model with the same independent variables and dependent variable to get these two indexes. All the tolerances were more than 0.1 and all the VIFs were less than 10 (see Table 6). It indicated that there was no obvious collinearity among the independent variables. Thus, all variables in Table 6 were used to regress in ordinal regression model.

3.3. Model description and model testing

SPSS 18.0 was used to conduct ordinal regression. Complementary log–log was the link function as it yielded the best results among logit, probit, negative log–log, complementary log–log and cauchit functions. Link function is a transformation of the cumulative probabilities of the dependent ordered variables that allows for estimation of the model. Complementary log–log function is recommended when the probability of higher category is high. A strict assumption has to be made when ordinal regression model is used. This is the parallel lines assumption. It is extremely important to carry out the test of parallel lines and if the assumption fails, the ordinal regression should not be used, and some alternative models with looser limitations, such as multinomial logistic regression model, are recommended. Parallel lines assumption means the regression coefficients are the same for all corresponding outcome categories. As we could see from Table 7, the statistical significance level of the general model was 1.000, so the parallelism assumption could not be rejected. That was, just a single set of coefficients was needed for all categories. Therefore, ordinal regression was suitable.

Besides test of parallel lines, Table 7 also provided model fitting information, the pseudo R-square, and the goodness of fit. Model fitting information is to test the null hypothesis (all the regression coefficients are zero except constant item). We could see that the two models were significantly different ($P = 0.000$), the null hypothesis was rejected and all the regression coefficients were not zero at the same time. The statistical significance level of Pearson and Deviance were 0.998 and 1.000, so the assumption that there was no obvious difference between predicted and observed value was accepted. The pseudo R-square evaluated the success of the model in explaining the variations of data. The interpretation of pseudo R-square in the ordinal regression model was similar to that of the R-square named Coefficient of the Determination in the linear regression model. The larger the pseudo R-square was, the better the model fitting was. Cox and Snell (0.547), Magelkerke (0.659) and McFadden (0.446) indicated that most proportion of variations in the outcome variables was accounted for by the predictor variables.

Table 4
Independent variable value table.

Independent Variable	Scale of measurement	Range
Gender	Nominal	1: Female 2: Male
Age	Ordinal	1: Between 18 and 30 years 2: Between 31 and 40 years 3: More than 40 years
Driving years	Ordinal	1: Less than 1 year 2: Between 1 to 3 years 3: Between 3 to 5 years 4: More than 5 years
Average annual mileage	Ordinal	1: Less than 10000 km 2: Between 10000 to 30000 km 3: More than 30000 km
Monthly income	Ordinal	1: Less than 5000 yuan 2: Between 5000 and 10000 yuan 3: More than 10000 yuan
Educational level	Ordinal	1: Middle school 2: University 3: Graduate
Driving style	Nominal	1: Risk-based 2: Steady 3: Conservative
Occupation	Nominal	1: Government employees 2: Company employees 3: Other occupations
Type of car	Nominal	1: Private car 2: Service car
Driving goal	Nominal	1: Saving time 2: Depending on circumstance 3: Saving fuel
Trust degree in VMS	Ordinal	1: High 2: Middle 3: Low
Familiarity with road network	Ordinal	1: Very familiar 2: Familiar 3: Not familiar
Route choice style	Nominal	1: Information type 2: Experience and information type 3: Experience type 4: Fixation type

3.4. Regression results and discussion

Parameter estimation result (see Table 8) displayed the ordered complementary log–log regression coefficients, the *p*-values of the coefficients and the 95% confidence interval for regression coefficients.

Significant regression coefficient means the corresponding variable is closely related to the log odds. That is to say, the corresponding factor has a close relationship with the guidance compliance behavior. Furthermore, the positive coefficients among the significant ones indicate that the log odds will increase with the increment of corresponding independent variable while the other variables keep unchanged, whereas the negative coefficients mean log odds decrease. Nine independent variables (*age*, *driving years*, *average annual mileage*, *monthly income*, *driving style*, *occupation*, the *degree of trust in VMS*, *the familiarity with road network* and *the route choice style*) of the guidance compliance behavior were significant at 0.05 level, while *gender* ($P = 0.244$) and *the type of car* ($P = 0.453$) were not significant.

Our conclusion about gender was inconsistent with the results of some previous studies (Bonsall, 1992b; Bonsall and Merrall, 1997; Conquest et al., 1993; Emmerink et al., 1996; Mannering et al., 1994; Wardman et al., 1997; Jou et al., 2005). Wardman et al. (1997) found that females in the sample were less sensitive to delay time. Jou et al. (2005) proposed that the tendency towards switching of male travelers was higher than females because of their probably lower tolerance level of congestion. The previous studies reached the conclusions that female drivers were found to be less willing to divert from their initially determined route. But in our study, the females and males were not significantly different. This may be due to the social progress, and their ideological concepts, social status and educational level etc. tend to be the same.

Table 5
Chi-square test between independent variables and dependent variable.

Independent variable	Progressive Sig. (two-tailed)	Whether to select or not
Gender	0.045	Yes
Age	0.018	Yes
Driving years	0.003	Yes
Average annual mileage	0.245	Yes
Monthly income	0.035	Yes
Educational level	0.996	No
Driving style	0.073	Yes
Occupation	0.249	Yes
Type of car	0.123	Yes
Driving goal	0.384	No
Trust degree in VMS	0.004	Yes
Familiarity with road network	0.034	Yes
Route choice style	0.000	Yes

Table 6
Collinearity statistics of independent variables.

Model	Collinearity Statistics		Whether to select or not
	Tolerance	VIF	
(constant)			
Gender	.841	1.188	Yes
Age	.815	1.227	Yes
Driving years	.645	1.551	Yes
Average annual mileage	.809	1.236	Yes
Monthly income	.814	1.228	Yes
Driving style	.846	1.182	Yes
Occupation	.902	1.109	Yes
Type of car	.833	1.200	Yes
Trust degree in VMS	.861	1.162	Yes
Familiarity with road network	.860	1.163	Yes
Route choice style	.905	1.105	Yes

Table 7
Model information.

Model	−2 Log likelihood	Chi-square	df	Sig.	
Test of parallel lines					
Null Hypothesis	232.659				
General	231.079	1.579	22	1.000	
Model fitting information					
Intercept only	427.304				
Final	232.659	194.645	22	.000	
Pseudo *R*-square			Goodness-of-fit		
Cox and Snell	.547		Chi-square	df	Sig.
Nagelkerke	.659	Pearson	370.014	448	.997
McFadden	.446	Deviance	315.188	448	1.000

Link function: complementary log–log.

Age significantly affected the guidance compliance behavior. The older the driver was, the higher the compliance rate was. The ordered log odds for drivers being 18–30 years old and 31–40 years old in a higher compliance degree were 1.505 and 1.023 less than drivers being more than 40 years old, respectively. That was, the compliance degree of drivers being over 40 years old was the highest, being 31–40 was higher, and being 18 to 30 was the lowest. Similar conclusions were found in some other researches. Bonsall and Joint (1991) suggested that young people were less inclined to comply with VMS advice. Wardman et al. (1997) found that a general tendency for drivers under 35 to be less sensitive to VMS message.

Table 8
Determinants of compliance rate (ordinal regression).

Independent variable	High vs. middle vs. low compliance rate		
	Estimate	Sig.	95%CI
Gender			
Female	0.239	.244	[-.163, 0.640]
Male	0[a]	.	.
Age			
18–30 years	−1.505	**.000**	[-2.344, -0.666]
31–40 years	−1.023	**.010**	[-1.807, -0.240]
over 40 years	0[a]	.	.
Driving years			
Less than 1 year	1.424	**.000**	[0.771, 2.077]
1–3 years	.413	.112	[-0.097, 0.931]
3–5 years	1.056	**.000**	[0.482, 1.630]
over 5 years	0[a]	.	.
Average annual mileages			
Less than 10000 km	−.733	**.039**	[−1.429, −0.036]
10001–30000 km	−.389	.260	[−1.067,0.288]
over 30000 km	0[a]	.	.
Monthly income			
less than 5000 yuan	−.325	.209	[−0.833, 0.182]
5000–10000 yuan	−.453	**.040**	[−0.886, −0.021]
Over 10000 yuan	0[a]	.	.
Driving style			
Risk-based	.681	.058	[−0.024, 1.386]
Steady	.821	**.001**	[0.329, 1.314]
Conservative	0[a]	.	.
Occupation			
Government employees	−.816	**.008**	[−1.423, −0.209]
Company employees	−.307	.229	[−0.808, 0.193]
Other occupations	0[a]		
Type of car			
Private car	.217	.453	[−0.350, 0.785]
Public car	0[a]		
Degree of trust in VMS			
High	.070	.815	[−0.654, 0.514]
Middle	.804	**.000**	[0.177, 1.290]
Low	0[a]	.	.
Familiarity with road network			
Very familiar	−.956	**.003**	[−1.587,−0.326]
Familiar	−.222	.345	[−0.681, 0.238]
Not familiar	0[a]	.	.
Route choice style			
Information type	1.828	**.000**	[0.908, 2.747]
Experience and information type	.425	**.034**	[0.032, 0.818]
Experience type	−.915	**.001**	[−1.478, −0.352]
Fixation type	0[a]	.	.

Link function: complementary log–log. The significance of bold value is 0.05.
[a] This parameter is set to zero because it is redundant.

The ordered log odds for drivers whose driving years were less than 1 year and between 3 and 5 years in a higher compliance degree were 1.424 and 1.056 more than driving years being over 5 years, respectively. Drivers with driving years being 1–3 years were not statistically different from drivers with driving years being over 5 years. Among the significant ones, drivers being less than 1 year complied with VMS the most, over 5 years the least. As novice drivers were lack of understanding and experience of VMS, they always had no idea about the better route when they encountered the route choice problem, so they would comply with the VMS, and the level of compliance was high. With the increment of driving years and driving experience, drivers had a better understanding of VMS, they gradually formed their own ideas through practical experience, and some of them might comply with the VMS after considering the experience and guidance information, resulting in a low compliance degree. It was consistent with previous work (Richards et al., 2004) which concluded that drivers with shorter driving years found VMS being more useful and experienced fewer problems while using VMS.

Drivers with average annual mileage being less than 10000 km were significantly different with the ones with mileage being more than 30000 km. The degree of compliance with mileage being less than 10000 km was lower than the reference

category. As we could see from the questionnaire data, drivers with average annual mileage being less than 10000 km were distributed in different intervals of driving years, and 32.6%, 34.8%, 18.1% and 14.5% for the four intervals, respectively. Furthermore, novice drivers were always accompanied with senior drivers, their behavior might be influenced by the supervisors. Also the trust degree in VMS of drivers with average annual mileage being more than 30000 km was obviously higher than the one with mileage being less than 10000 km, and some of them were professional chauffeurs, i.e., they were the most experienced drivers. Groeger (2000) proposed that driving experience influenced not only the driving task itself, but also concurrent tasks other than driving. The drivers with mileage being over 30000 km seemed to be able to time share multiple tasks and had a highest understanding of the VMS, so they were inclined to comply with the VMS.

Personal monthly income had a definite relation with guidance compliance behavior. The degree of compliance increased with the rise of monthly income. The log odd of drivers with monthly income being 5000–10000 yuan in a higher compliance degree was 0.453 less than the ones with monthly income being over 10000 yuan. The highest income group complied with the VMS at the highest level. It was consistent with the results of some other researchers. Jou et al. (2005) found the tendency towards switching routes of higher income persons was higher with the provision of real-time traffic information and had a better understanding of the traffic condition. Higher income group seemed to have a higher value of time. They expected to use more external information to select the shortest path and save more time.

Driving style affected the compliance rate in a certain degree. Compared with conservative drivers, steady ones were significantly different but risk-based ones were not. The difference between the log odds of steady and conservative ones was 0.704. The steady drivers could judge the traffic conditions the most impersonally among the three styles, so they were more likely to follow with VMS and regard it as a complementary tool. This was consistent with the age effects on compliance rate, the proportion of steady driver increased from 67.2% among the drivers being 18–30 years old to 73.3% among drivers being over 40. Therefore, the compliance rate increased correspondingly.

Occupation also affected drivers' compliance rate. Compared with the drivers with other occupations, the government employees varied significantly but the company employees did not. The government employees had low compliance inclination. According to our analysis, we held that their low compliance rate was related to their characters and working nature. The questionnaire data demonstrated that the proportion of risk-based drivers among the government employees was the smallest (6.7% among government employees, 11.2% among company employees and 11.8% among the other occupations). This suggested that government employees were more confident and risk-averse in their decision-makings. They were unwilling to bear delay risks of inaccurate guidance information, but more willing to rely on fixed path or experiential path.

Trust degree in VMS was also a key factor. Previous researches (Bonsall and Joint, 1991; Hato et al., 1995; Janssen and Vander Horst, 1992; Zhao et al., 1995) had demonstrated that compliance with guidance advice was highly dependent on the trust degree of that advice as judged from its previous performance. Compared with the drivers who distrusted the VMS (i.e., trust degree was low), the drivers who generally trusted it (i.e., trust degree was middle) had a higher compliance rate.

The familiarity with a road network played a role in guidance compliance behavior. Compared with the drivers unfamiliar with network, the very familiar ones were not inclined to comply with VMS. Wardman et al. (1997) provided that some previous researches (Bonsall and Joint, 1991; Hato et al., 1995; Mahmassani and Chen, 1991) had suggested that the familiarity with a network was likely to reduce the desire to comply with guidance while increasing the ability to respond to traffic information. For example, Bonsall and Joint (1991) investigated 100 drivers whose cars mounted with vehicle guidance system and found that 70% of the drivers complied with the guidance when they were familiar with the network, but 90% when unfamiliar with.

Route choice style affected the drivers' compliance behavior significantly. Compared with the drivers being fixation type, the log odds of the experience type and the experience and information type were 1.802 and 0.452 more, and the log odd of the guidance information type was 0.894 less. It indicated that the compliance rate from the highest to the lowest was as follows: guidance information type, experience and information type, fixation type and experience type. As we declared above, the real fixed or experienced drives had nothing to do with guidance compliance rate, but the drivers always judged themselves with a deviation from the actual. In fact, the participants we chose to be analyzed in the model were all experience and information type.

4. Simulation and analysis

4.1. Simulation environment

At present, The VMS shows the drivers the nearly real-time information which represents the road conditions in 5 min, but we doubt if VMS should show drivers the processed information, such as predicted road conditions after considering drivers' next behaviors, to achieve a better guidance effect. The mode releasing the almost-real-time information is called ordinary guidance mode (M1), and the one releasing the information based on the flow forecasting is called predicted guidance mode (M2). Simulation on MATLAB based on cellular Automata model was used to simulate drivers' route choice behaviors when crossing the SITONG Bridge under M1 and M2. The length of cellular was 7 m. 10000 s was simulated in each simulation. Concrete simulation environment was set according to the data of investigation and regression results (Table 9).

Table 9
Simulation environment.

Item	Concrete experimental conditions
Travel destination	D1, D2, D3 (60% of drivers headed for D1, 20% for D2 and 20% for D3)
Travel speed	See Table 2
Travel delay	See Table 3
Driver type	T1, T2, T3 (10% of drivers were T1, 41% were T2 and 49% were T3)
Compliance rate	0.7 for T1, 0.5 for T2 and 0.3 for T3
Guidance cycle	300 s
Guidance mode	M1 and M2

4.2. Simulation results and analysis

Ordinary guidance mode and predicted guidance mode were applied separately to simulate the traffic flows, and in order to verify the effectiveness of these two modes, average speeds of three main roads (the section from the SITONG Bridge through JIMEN Bridge to XIZHIMEN Bridge was called left road, the section from the SITONG Bridge to BAISHIXIN Bridge was called middle road, and the section from SITONG Bridge through SUZHOU Bridge to ZIZHU Bridge was called right road) and the average travel time of drivers with different destination areas (D1, D2, D3 and all destination areas) under the two modes were calculated from simulation results. Figs. 4 and 5 showed the average speeds of left, middle and right roads under M1 and M2. There were large fluctuations among inter- and intra-groups under M1, which indicated that the road conditions were very unstable. But under M2, fluctuations among the inter-groups, especially on left road and right road, decreased sharply. It was obvious that drivers would choose their most beneficial roads when road conditions were shown to them.

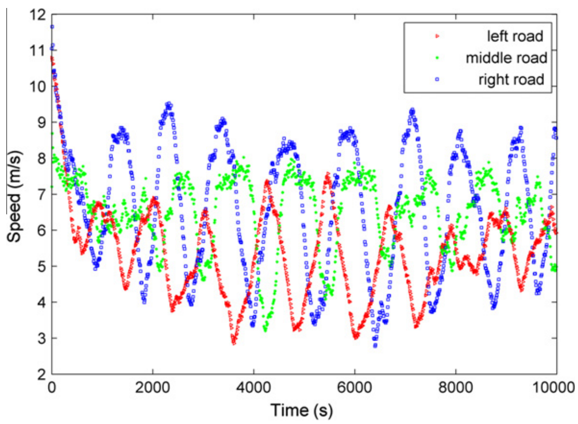

Fig. 4. Average speeds of three main roads under M1.

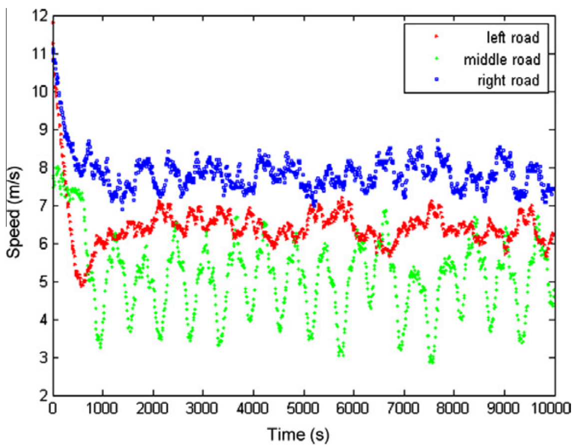

Fig. 5. Average speeds of three main roads under M2.

When the almost-real-time information was presented, most of the drivers had the same current optimal path, and the cluster of drivers resulted in the large fluctuations with the congestion of optimal path and smoothness of the alternative paths. However, the predicted information had taken the drivers' next selections into consideration, which was more likely to guide the drivers to achieve a balanced state. Fig. 6 showed the average travel time of drivers under M1 and M2. Compared with the travel time under M1, the average travel time of drivers with D1, D2, D3 and all destinations under M2 reduced from 1104.63 s to 952.08 s, 824.00 s to 744.90 s, 493.25 s to 435.19 s and 946.01 s to 817.07 s, decreased by 13.81%, 9.6%, 11.77% and 13.63%, respectively.

Through the comparison of two guidance modes, M2 was proven to be more effective than M1, and 11 typical suggestions of releasing predicted guidance information were summarized from simulation results to improve traffic guidance effect (Table 10). Actual road conditions were the almost-real-time congestion information calculated from the road conditions in one guidance cycle. As suggestion 's8' presented, when the left and middle roads were all generally crowded and right road was smooth (YYG), drivers were informed that the left road was generally crowded, but the middle road and right road were smooth (YGG). The shapes of flow-density curves of three main roads were also obtained from field observation to illustrate the reasons (Fig. 7). The flow-density curves of left road and right road were similar, but very different from the curve of middle road as the control delays decreased the traffic capacity of middle road. We carried out the simulation of drivers' route choice behaviors when drivers were informed that the three main roads were 'YYG' under M1 and 'YGG' under M2 while the actual road conditions were the same 'YYG' road conditions. Based on the flow-density curves, the traffic flows could be calculated if the densities were known. Thus densities of three main roads were estimated every 5 s during a whole guidance cycle (300 s) immediately after 'YYG' and 'YGG' were presented to drivers separately, and the corresponding flow curves were easily shaped (Fig. 8). Compared with M1, the flows of middle road and right road under M2 increased while the flow of left road decreased, and the total flow of three main roads under M2 was higher than the one under M1, which meant the total rising amplitude of middle and right roads should be larger than the decreasing amplitude of left road under M2. During the simulation of one guidance cycle, 68.89% of drivers chose left road to go, 5.56% chose middle road and 25.55% chose right road when 'YYG' were shown to drivers, but 46.26%, 30.61% and 23.13% when 'YGG' were shown. And the average densities of left, middle and right roads during the cycle were 0.0486 veh/m, 0.0147 veh/m and 0.0206 veh/m under M1, and were 0.0353 veh/m, 0.0241 veh/m, 0.0297 veh/m under M2, respectively. The corresponding density variation sections and the values of start and end points were marked in the flow-density curves (Fig. 9), the curvature of left descending section

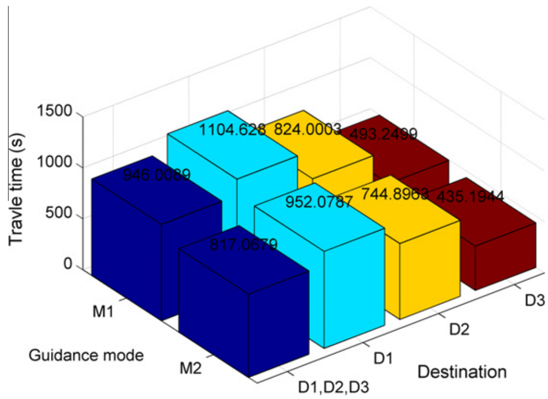

Fig. 6. Average travel time of drivers with different destinations.

Table 10
Suggested guidance information based on the actual road conditions.

Number	Actual road conditions			Predicted road conditions		
	Left road	Middle road	Right road	Left road	Middle road	Right road
s1	Y	Y	Y	Y	G	G
s2	Y	G	R	Y	Y	R
s3	R	G	G	Y	G	G
s4	Y	G	G	Y	Y	G
s5	G	G	G	G	Y	G
s6	G	R	G	R	Y	Y
s7	Y	G	Y	G	G	G
s8	Y	Y	G	Y	G	G
s9	Y	R	G	G	R	G
s10	Y	R	Y	G	R	G
s11	R	Y	G	Y	G	G

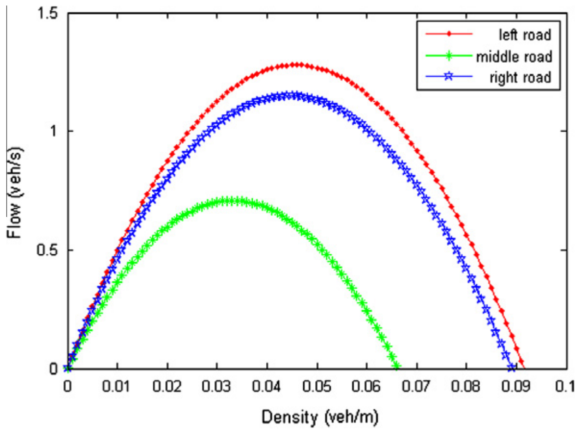

Fig. 7. The flow-density curves of three main roads.

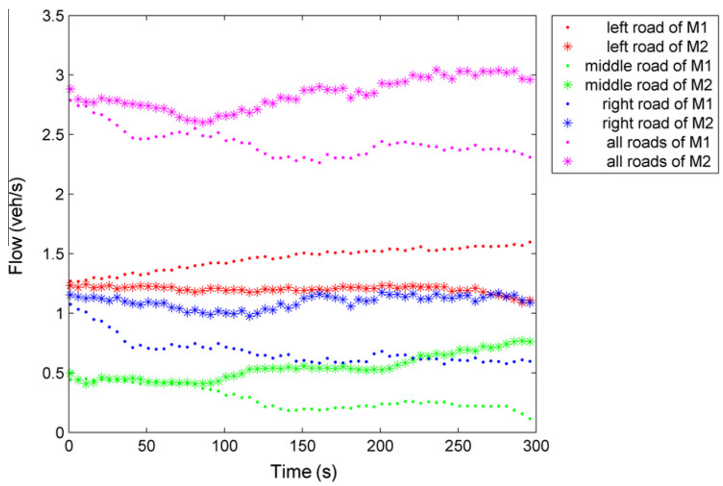

Fig. 8. The flow fluctuations of three main roads under M1 and M2.

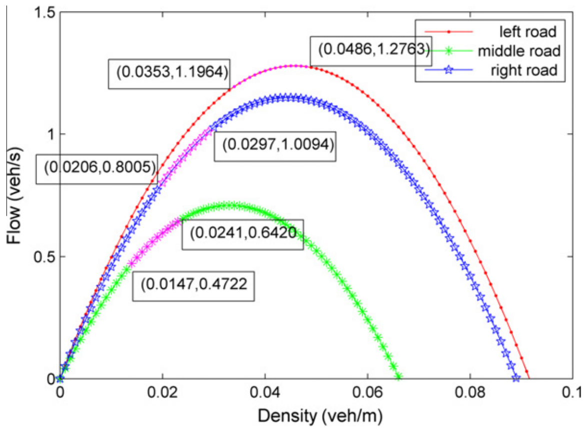

Fig. 9. The variation sections of flow-density curves.

was smallest and the flow reduced from 1.2763 veh/s to 1.1964 veh/s, the curvatures of middle and right ascending sections were more larger and the flows increased from 0.4722 veh/s to 0.6420 veh/s and 0.8005 veh/s to 1.0094 veh/s, it was apparently that the sum of increments (0.6420–0.4722 + 1.0094–0.8005) were much larger than the decrement (1.2763–1.1964).

5. Conclusions

This paper had dealt with the daily route choices behaviors and its influencing factors under nearly real-time information shown on VMS in the urban network of Beijing, China. The route choice decisions of different drivers under large-scale simulation scenes were combined with their socio-economic and travel characteristics in the questionnaire to extract the candidate factors. It was important that we proposed an accurate method to calculate the compliance rate of each driver by considering the relation among the suggested path of VMS, actual chosen path and experiential path of the driver, and the driver's trust degree in VMS. Accurate compliance rate made the results more persuasive. Ordinal regression by SPSS was used to analyze and evaluate the impacts of different factors. Although the influencing factors of route choice behaviors have been studied in previous researches, regression analysis based on the data from questionnaire in compliance behavior has not been used as often as simulation or theoretical model. Finally, a more effective information release mode was confirmed through simulation and some detailed suggestions of releasing specific information were presented to practical application.

Guidance compliance behavior, including route choice behavior is a very regular activity of drivers, but most of the drivers cannot always make their best choice. Seldom could keep choosing the optimal path and judge their selections timely and accurately in our survey. It is because drivers could not perceive or behavior fully rationally while the external influencing factors keep changing. For the design and improvement of guidance systems, the characteristics of compliance behavior should be taken into full account. Accurate compliance rates of drivers with different preferences, habits or experience are needed in order to modify guidance algorithm and assess the guidance effect, finally to better balance the traffic load and resource and increase network utilization rate.

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